CHAPTER 4

From the Ground Up:

The Path from Experiment to Operations

In the decade of the 1960s the Air Force turned its plans for military spacefaring into functioning systems. While manned spaceflight remained the centerpiece of the Air Force space agenda, the plans and programs for unmanned, automated satellites developed in the last Eisenhower administration now became reality. Communications, navigation, weather, and surveillance spacecraft came of age during the era that spanned the Kennedy, Johnson, and Nixon administrations.

Although the Defense Department proved unwilling to support the broad-based, Air Force-led military space program advocated by its leaders, the Air Force nonetheless forged ahead with development of spacecraft and the infrastructure to support them. The rapid pace of technological development over the course of the decade made possible more sophisticated instrumentation for these spacecraft. Equally important, developments in rocket boosters and the Air Force's efforts to achieve a more powerful, standardized launcher fleet produced reliable space boosters with greater lifting capacity capable of placing upper-stage vehicles like the Agena D and its satellites into geosynchronous orbit. Increasingly complex and larger satellites carried multiple payloads and performed a wide range of operational functions in space. At the same time, engineers succeeded in extending the lifetimes of satellites in orbit, thereby reducing the number of spacecraft needed. To support expanding satellite and booster capabilities, the Air Force created an elaborate space infrastructure of launch facilities, tracking and control networks, and research and development offices and laboratories. Taken together, the enormous growth in space capabilities by the early 1970s increasingly propelled space systems from the realm of research and development to the broader arena of operational applications.

Even though it could never achieve sole responsibility for military space, the Air Force found itself at the center of this fundamental transition. Critics rightly bemoaned the fragmented nature of military space responsibilities and organization that developed in the late 1950s and 1960s and that produced unnecessary delays, confusion, and severe security restrictions. General Bernard Schriever and other Air Force leaders valiantly attempted to have the Air Force assume ARPA's potential role as the sole military space agency equivalent to NASA on the civilian side. The Defense Department disagreed, and pursued a policy of tri-service management of space development in the name of cost-effectiveness and service cooperation rather than contention. Although the Air Force had achieved the dominant military space role through its authority to develop and launch military space systems and provide support to NASA, its more ambitious agenda would remain unrealized. As a result, by default, Air Research and Development Command and its successor, Air Force Systems Command, the Air Force's research and development organization, retained operational responsibility for the majority of space programs and systems for the Air Force and other space agencies. This set the stage for the intra- and interservice conflict over space roles and missions that would occur in the 1970s. Nevertheless, a fragmented military space program did not prevent the military space community—led by the Air Force—from compiling an enviable record of accomplishment. By the early 1970s military space dividends had become increasingly apparent at least to commanders who benefited from space-based systems in the Vietnam conflict and elsewhere. Instrumented earth satellites now offered the promise of providing the revolutionary applications predicted by space visionaries many years earlier.

Artificial Earth Satellites Become Operational

Seeking Global Communications—From Courier and Advent to the Defense Satellite Communications System (DSCS). The Second World War demonstrated the essential military need for electronic communications of longer ranges, greater security, higher capacities, and improved reliability. Orbiting earth satellites first proposed in 1945 by Arthur C. Clarke offered a revolutionary means of meeting these requirements. The British science fiction writer had suggested placing three satellites in geosynchronous orbit around the earth's equator. Equally spaced, they would put nearly every area on the earth within line-of-sight of one of the satellites; the spacecraft would receive signals from Earth and retransmit them back to Earth by means of solar power. Clarke's concept of synchronous repeater communication satellites attracted serious military interest, but remained only a theoretical possibility until technology could provide effective spacecraft and the boosters to place them in orbit.[1]

Immediately after the war, the Army experimented with passive relay space communications by using the moon and the planet Venus as signal reflectors. In the early 1950s the Navy also successfully bounced voice messages off the moon, and by the end of the decade had created two-way voice transmission between Washington and San Diego, then Washington and Hawaii using the earth's natural satellite. The Navy's project Communications by Moon Relay represented the nation's first operational space communications system and, except for navigation, the initial military application employing a satellite, in this case a natural one.[2]

After considering a number of proposals, the Defense Department's Advanced Research Projects Agency (ARPA) in July 1958 assigned the Army Project SCORE (Signal Communications by Orbiting Relay Equipment). On 18 December of that year an Air Force Atlas B booster launched the active (rebroadcasting) satellite into low-earth orbit, where on very high frequency (VHF) it broadcast President Eisenhower's recorded Christmas message. The Army followed this achievement in October 1960 with the successful launch of its Courier delayed-repeater communications satellite, which operated at ultra high frequency (UHF) in low-altitude (90-450 nautical miles) orbit. Meanwhile, the Air Force contracted with MIT's Lincoln Laboratory to produce 480 million hair-like copper dipoles, which, under Project West Ford, were launched on 9 May 1963 and reflected radio signals from an orbit nearly 2,000 nautical miles above the earth. Although initially scientists worried about potential interference with their radio telescopic observations, the dipoles ultimately proved benign, degraded rapidly, and three years later had completely disappeared.[3]

In the late 1950s military planners took another step on the road to translate into reality Arthur Clarke's dream of a global satellite communications system. In 1958 ARPA directed the Army and Air Force to plan for an equatorial synchronous (strategic) satellite communications system, with the Air Force responsible for booster and spacecraft, and the Army for actual communications elements aboard the satellite as well as on the ground. The program initially consisted of three projects: two, Steer and Tackle, involved medium-altitude repeater satellites; the third, Decree, called for a synchronous repeater satellite using microwave frequencies. In September 1959, the Secretary of Defense transferred communications satellite management responsibility from ARPA to the Army. Six months later, in February 1960, the Defense Department combined the three projects into a single program, Project Advent, and that September assigned it to the Army. In the meantime, it became apparent that neither the Army nor any other single service would have overall management responsibility for an operational military satellite communications (MILSATCOM) capability, because in May 1960 the Defense Department combined the strategic communication systems of the three services under a Defense Communications System (DCS) run by the newly created Defense Communications Agency (DCA).[4]

In the words of one observer of communications satellite developments, Advent proved to be "a not quite possible dream."[5] The ambitious program called for 1250-pound solar array-powered satellites, stabilized on all three axes, with the first group to be placed in a 5600-mile inclined orbit by Atlas-Agena B vehicles. The second set would achieve synchronous equatorial orbits when launched by the Atlas-Centaur booster combination. But Advent suffered from cost overruns, inadequate payload capability, and excessive satellite-to-booster weight ratios. At the same time, technology had advanced to the point where smaller satellites of 500 pounds or less could perform the same mission effectively. Advent's problems compelled Secretary of Defense Robert McNamara to cancel the program on 23 May 1962.[6]

With Advent's demise, Defense Department officials turned their attention to two alternatives that the Aerospace Corporation had been studying for the Air Force. In the summer of 1962 Secretary McNamara sanctioned the first Air Force proposal, which proposed randomly placed, medium-altitude (approximately 5,000 miles), nonstabilized satellites weighing 100 pounds each. He assigned the Air Force Systems Command's Space Systems Division responsibility for developing the spacecraft and communications payload and satellite operations. Unlike Advent, responsibility for orbiting elements would not be divided; the Air Force would handle spacecraft development and launch, while the Army's Satellite Communications Agency received authority to handle only the ground communications segment. Now termed the Initial Defense Communication Satellite Program (IDCSP), this would be another interservice project in which the Defense Communications Agency would coordinate Air Force and Army efforts to ensure compatibility. At the same time, the Air Force received permission to continue studies on a second alternative, which called for a future, stabilized synchronous system, later designated the Advanced Defense Communications Satellite Program (ADCSP).[7]

Progress toward full development of IDCSP proved difficult. In the spring of 1963, the Air Force received industry proposals for program definition studies based on using the Atlas-Agena D as the launch booster combination. Characteristically, the McNamara Defense Department required numerous studies and evaluations before funding an expensive new program, but the main reason for delay involved the new Communications Satellite (COMSAT) Corporation, established by Congress in early 1963. Before authorizing a more realistic MILSATCOM project to replace Advent, Secretary McNamara opened discussions with the COMSAT Corporation. McNamara questioned why the Pentagon should fund a separate, costly, medium-altitude MILSATCOM system if the Defense Department could lease links from COMSAT Corporation to satisfy military requirements at lesser cost. The Defense Department and COMSAT Corporation, however, could not agree on costs or the need for separate military repeaters aboard the commercial satellites.[8] Furthermore, the addition of military applications to a civilian system designed for use by other countries created international concerns. On 15 July 1964, after months of fruitless effort, Secretary McNamara ended the negotiations and opted for full-scale development of a dedicated military system, long favored by the Air Force to ensure security and reliability.[9]

By August 1964, when President Johnson announced immediate development of a military communications satellite system, the project had undergone a major change. The Defense Department decided to forego the medium-altitude system for the near-synchronous equatorial satellite configuration. The major incentive for the change proved to be the new launch vehicle under development, the Titan III, whose greater payload and altitude capabilities offered the prospect of launching a number of small satellites simultaneously into synchronous orbits. Defense officials elected to proceed with the more ambitious program despite concerns about solar heating at higher altitudes, the need to modify the original Philco-Ford satellites, and reliance on a booster yet to be launched. Taking a deliberate approach to reach synchronous orbit, the plan's first phase called for launching eight satellites into a near-synchronous equatorial configuration at nearly 21,000 miles in altitude rather than a more challenging synchronous orbit over 1,000 miles higher. Planners worried that, without "station keeping" capability, the satellites orbiting at the higher geosynchronous altitude might drift out of the desired position.[10]

Originally expected to function as an experimental system, IDCSP rapidly proved its operational worth and became the first in a three-phase evolutionary program to provide long-haul, survivable communications for both strategic and tactical users. The first seven IDCSP satellites, relatively simple in design to avoid the problems that had hampered Courier and prevented Advent from even getting off the ground, went aloft on 16 June 1966. Operating in the super high frequency (SHF) bandwidth, weighing about 100 pounds each, and measuring only three feet in diameter and nearly three feet in height, these spin-stabilized, solar-powered satellites contained no movable parts, no batteries for electrical power, and only a basic telemetry capability for monitoring purposes. The configuration of each IDCSP platform provided two-way circuit capacity for either eleven tactical-quality voice or five commercial-quality circuits capable of transmitting one million digital or 1,550 teletype data bits per second. The IDCSP satellite's 24-face polyhedral surface accommodated 8,000 solar cells that provided sufficient energy to power a single-channel receiver operating near 8,000 megahertz, a three-watt traveling wave tube (TWT) power amplifier transmitting in the 7,000 megahertz range, and one 20-megahertz double-conversion repeater. To launch the satellites, engineers placed them in a lattice framework mounted above the final booster, from where they would be released one at a time.[11]

On 16 June 1966, the Titan IIIC's fourth development flight successfully launched the first seven IDCSP satellites, along with an eighth experimental satellite designed to perform tests of gravity-gradient stabilization at high altitudes. Placing the satellites in almost exactly equatorial and nearly circular orbits involved the most complex series of orbital operations heretofore conducted in space. Buoyed by their initial success, IDCSP officials on 26 August 1966 launched a second set of eight satellites. But the fairing covering the satellites and its dispenser failed, and the Titan booster had to be destroyed eighty seconds after launch. With a redesigned fairing in place, a third launch on 18 January 1967 placed eight satellites into nearly the same orbits, while three additional IDCSP satellites joined their predecessors with a launch on 1 July. The latter flight also included three experimental satellites: a Navy gravity gradient spacecraft (*DODGE 1*); a despun antenna test satellite (*DATS 1*); and the fifth in the series of important Lincoln Laboratory experimental tactical satellites (*LES*-5). The final IDCSP Phase I group of eight satellites achieved orbit on 13 June 1968. With the last of the twenty-six satellites placed into proper orbit, the Defense Communications Agency declared the system operational and changed its name to Initial Defense Satellite Communications System (IDSCS).[12]

In mid-1968, thirty-six fixed and mobile ground terminals completed the satellite communications system. Originally designed for project Advent and later used in NASA's commercially targeted Synchronous Communication (Syncom) satellite program, two fixed AN/FSC-9 terminals with 60-foot diameter antennas, one located at Camp Roberts, California, and the other sited at Fort Dix, New Jersey, underwent modifications and began relaying IDSCS satellite data as early as mid-1968. Mobile terminals consisted of seven AN/TSC-54 terminals with 18-foot antennas and thirteen AN/MSC-46 terminals with 40-foot antennas. Additionally, the system included six 6-foot ship-based antennas. By the end of the decade officials were hard at work improving reliability and increasing terminal channel capacity. Additional ground terminal locations included Colorado in the United States, West Germany in Europe, Ethiopia in Africa, and Hawaii, Guam, Australia, Korea, Okinawa, the Philippines, South Vietnam, and Thailand in Asia.[13]

Already, by 1968, the new military satellite communications system had proved its value. A year earlier, the Air Force had established a link to Vietnam and publicly demonstrated its capability that summer at the 21st Annual Armed Forces Communications and Electronics Association convention in Washington, D.C. During the festivities Air Force Secretary Harold Brown spoke directly with the Deputy Commander for Air and Seventh Air Force Commander, General William Momyer, in Saigon, South Vietnam, about that day's air operations.[14]

The global IDSCS later became known as the Defense Satellite Communications System, Phase I, or DSCS I. Its exceptional reliability proved a very pleasant surprise to all involved in the project. By late 1971, fifteen of the twenty-six first-phase satellites remained operational. While several turned off after six years, as programmed, in mid-1976 three continued to function. The initial satellite system provided the Defense Communications Agency good service for nearly ten years. The IDSCS design, moreover, furnished the basic configuration for the communications satellites in the British Skynet and North Atlantic Treaty Organization (NATO) satellite programs that Air Force Thor-Delta boosters launched successfully in 1969 and 1970, respectively.[15]

Although the initial military communications satellites proved superior to available radio or cable communications, they remained limited in terms of channel capacity, user access, and coverage. Furthermore, military planners worried about the vulnerability of a command and control system that involved a central terminus connected to a number of remote terminals. The DSCS II design sought to overcome these deficiencies. Representing what planners had envisioned for Advent ten years earlier, DSCS II would encompass secure data and command circuits, greater channel capacity, and radiation protection features. In 1964 Secretary McNamara authorized preliminary work on the concept for a synchronous system offered by the Air Force after Advent's cancellation. In 1965 the Defense Communications Agency awarded six study contracts for concept definition. After numerous changes, in June 1968 the Defense Department approved the concept for procurement, and in March 1969 TRW Systems received the contract from Air Force Systems Command's Space Systems Division (formerly SAMSO) to develop and produce a qualification model and six flightworthy satellites that would be launched in pairs aboard a Titan III. Plans called for a constellation of four active satellites in geosynchronous orbit, supported by two orbiting spares. One satellite would be positioned over the Indian Ocean, one each over the eastern and western Pacific Ocean, and one over the Atlantic Ocean. Again emphasizing interservice development, the Defense Communications Agency would retain overall system management, with the Army responsible for ground terminals, and the Air Force responsible for the space segment, which included satellite acquisition, launch, and on-orbit operational control through the Sunnyvale, California, control facility's S-band space-ground link system.[16]

DSCS II represented a "giant step" in technical development over its smaller, lighter, and less capable predecessor. Each satellite measured nine feet in diameter, thirteen feet in height with its antennas extended, weighed 1,300 pounds, and was dual-spun for stability. An outer portion, consisting of an equipment platform, much of the satellite's structure, and cylindrical solar arrays, was spun to achieve stabilization. The inner section, housing X-band communications equipment and antennas, used a motor to despin, or remain stationary while the outer portion revolved around it, in order to keep the four communications antennas always pointed to the earth. Two horn antennas provided broad-area earth coverage, while two parabolic reflectors supplied narrow-beam coverage. The flexible, four-channel configuration provided a variety of communication links for achieving compatibility with various-size terminals. It possessed capacity for 1,300 two-way voice channels or 100 million bits of digital data per second, and rechargeable on-board batteries generated 520 watts of power to complement the satellite's eight solar panels. The five-year design life nearly doubled that of DSCS I, and the new system's redundancy, multichannel and multiple-access features and increased capability to communicate with smaller, more mobile ground stations especially pleased the Air Force and other users. While program officials readied the satellites for an initial late 1971 launch date, they proceeded to modify twenty-nine IDSCS ground terminals and build additional medium and heavy mobile and shipboard terminals for use with DSCS II.[17]

The orbital history of DSCS II satellites in the 1970s, beginning with launch of the first pair on 2 November 1971, revealed a somewhat spotty performance record. A Titan IIIC placed the first two DSCS II satellites into synchronous orbit, one positioned over the Atlantic Ocean and one over the Pacific Ocean. Problems occurred almost at once, when the first satellite's on-board receiver failed to respond to command signals and the absence of any telemetry signals from the second rendered it temporarily lost in space. Although Air Force technicians and engineers eventually succeeded in controlling both satellites, the Pacific satellite failed after ten months and the Atlantic satellite after nine months of operation. As a result, the Defense Department elected to continue using the IDSCS satellites until engineers could redesign the next two satellites. After balancing the despun platform and modifying the power-distribution system, the second pair of satellites was successfully launched and deployed on 13 December 1973. By February 1974, their performance convinced officials to declare DSCS II operational. Yet the launch of the final two satellites on 20 May 1975 proved disastrous. When the Titan IIIC's inertial guidance failed, the satellites deployed into low orbit and vaporized six days later during reentry. With only two satellites now operational, the Air Force responded by contracting with TRW for an additional six satellites of the original design and, later, four more with 40-watt TWT amplifiers in place of the 20-watt amplifiers. Despite another launch failure in March 1978 and continued high-voltage arcing in the power amplifiers, by the early 1980s the DSCS II constellation would not only fulfill global, strategic communications requirements through 46 DSCS ground terminals, but would also link the Diplomatic Telecommunications System's 52 terminals and the Ground Mobile Forces' 31 tactical terminals. Perhaps the best example of the satellite's durability is that DSCS II B4, launched on 13 December 1973, would last four times longer than its design life; and the Air Force would not turn it off until 13 December 1993. Meanwhile, in 1974 the Air Force began designing an improved DSCS III satellite to meet the military's need for increased communications capacity, especially for mobile terminal users, and for greater survivability.[18]

The Defense Satellite Communications System represented a global, strategic communications system. While the Air Force, in DSCS II, developed an operational strategic communications system, it also joined other agencies to produce an operational tactical satellite communications network. The road to tactical satellite communications took two paths. One involved Air Force activity that began in earnest in 1959 as part of ARPA's effort to develop a synchronous communication satellite. Although the Air Force supported the modest ARPA program, it focused on the Strategic Air Command's requirement for communications with its aircraft fleet in the polar region. As noted earlier, the ARPA concept could not meet this need, and the program became "reoriented" into three separate functions. Of the three, Steer proved most important for the Air Force because it envisioned satellites in polar orbit at 5,600 miles altitude capable of providing a single channel between aircraft and ground stations. But in the May 1962 reorientation that resulted in a single Advent program, Steer was canceled and, soon thereafter, officials terminated the program elements that had supported tactical communications.[19]

Air Force interest in tactical communications by satellite, however, did not diminish. With the conclusion of the passive West Ford dipole program in 1963, the Lincoln Laboratory turned its attention to active systems and began what would become a long history of tactical experimental satellite development. In short order MIT's laboratory produced a series of six Lincoln Experimental Satellites (LES) to test the technology for satellite-based communications with small mobile ground terminals. Over the life of the program, the Army and Navy participated by establishing UHF terminals on ships, submarines, jeeps and other small vehicles. The Lincoln satellites normally hitched a ride "piggyback" as a secondary payload on space launches. The first Lincoln satellite, *LES-1*, for example, entered orbit as part of a multiple-satellite payload aboard a Titan IIIA on 11 February 1965. Of the six satellites placed in orbit during the decade, the final two proved most significant for future tactical operational development. By 1 July 1967, when *LES-5* joined the three IDCSP satellites in subsynchronous orbit, technology had progressed to the point where the scientists could produce a 230-pound satellite with solid-state equipment capable of evaluating electronic despin logic. This proved important in developing DSCS II stabilization technology. *LES-5* remained operational until May 1971. Meanwhile, *LES-6*, the last experimental satellite, had been lofted into synchronous orbit by a Titan IIIC on 26 September 1968 along with three Office of Aerospace Research experimental satellites. *LES-6* represented a major technological advance over the *LES-5* that had been launched the previous year. Weighing nearly 400 pounds, *LES-6* housed a more powerful, all-solid-state UHF communications repeater and possessed electronic antenna despin capability. By connecting its amplifier directly to the satellite's solar array, scientists ensured that it would not compete for power with other equipment. Like its predecessor, *LES-6* also conducted experiments to measure the electromagnetic environment in space using a UHF radiometer.[20]

A second path on the way to operational tactical satellite communications involved a tri-service effort that, by late 1965, had agreed on producing a large satellite that would orbit at geosynchronous altitude. It would be designed with high-powered communications repeaters dedicated to the military UHF and super high frequency (SHF) wavelengths, with cross connections to other orbiting satellites, and the capability of switching bandwidths as desired. In December 1966, the Defense Department awarded Hughes Aircraft Company the satellite contract.[21]

TACSAT, as this satellite came to be called, represented "state of the art" communications technology. Measuring nine feet in diameter and twenty-five feet in height with antennas extended, and weighing 1,690 pounds, the cylinder-shaped spacecraft emerged as the largest communications satellite of its time and the first to be dual-spun for stability. Significant electronic, structural, and mechanical advances characterized its design and development. Generating one kilowatt of solar power, it possessed a 40-voice channel UHF capacity and an X-band capability of 40 voice circuits directed to a terminal on Earth with an antenna as small as three-feet. TACSAT's solid-state components provided 350 watts of power for UHF transmissions and 40 watts for SHF requirements using two traveling-wave tube amplifiers.

Unfortunately, funding limitations restricted the program to a single satellite. As a result, engineers and program managers conducted exceptionally thorough and challenging tests before declaring the satellite ready. On 9 February 1969, a Titan IIIC launched from Cape Kennedy and placed TACSAT into a near-synchronous 19,300 nautical mile orbit above the equator. Its performance exceeded all expectations. In March, twenty ship and land stations from Bermuda to Hawaii conducted a tri-service roll call, in which Air Force representatives successfully participated from Los Angeles using a battery-powered 22-pound portable transmitter and a six-pound receiver. On orbit for thirty-four months before an attitude control failure ended its operational capability, TACSAT well served the military by supporting a number of operations, including the recovery of *Apollo 9* in the Atlantic Ocean on 13 March 1969 by linking the carrier *USS Guadalcanal* recovery ship directly with the White House.[22]

The success of TACSAT also intensified interest in developing a tactical communications system for the Navy that could link ships, shore installations, and aircraft. Concept development, with Air Force participation, commenced in 1971 on a four-satellite, near-synchronous equatorial configuration that would become known as the Fleet Satellite Communications (FLTSATCOM) Program. Although the Navy provided funding and ground terminals, the Air Force served as the Navy's agent in all spacecraft areas and received use of a portion of the system's capacity. The Air Force realized that participation in the Navy's program could satisfy its long-term need for global tactical communications for its strategic aircraft. Meanwhile, the success of TACSAT could not prevent the program's termination on the basis of high cost. After several reconfigurations, the project reemerged as the Air Force portion of the FLTSATCOM. In effect, the Air Force Satellite Communications (AFSATCOM) System would use current and planned FLTSATCOM spacecraft to provide global communications for strategic Single Integrated Operations Plan (SIOP) forces. The planners expected to launch the first of the four satellites in the late 1970s.[23]

In the decade ahead, planners faced daunting challenges in their efforts to master the new communications technology in order to provide operational service to an ever-increasing number of users. Along the way, they would have to fend off more attempts from cost-cutters to combine the nation's civilian and military communications systems. Nevertheless, despite the rocky course, communications satellites had proven their value, and a global network of tactical and strategic space-based communications appeared on the horizon. By the early 1970s, the Air Force had begun to fulfill the dream of Arthur Clarke and the designers of Advent for point-to-point worldwide communications by placing sophisticated communications satellites in synchronous equatorial orbits.

Watch on the Weather—From TIROS to the Defense Meteorological Satellite Program (DMSP). Meteorological satellites comprise a second functional category of artificial earth satellite support to tactical and strategic military operations. Like Arthur Clarke and other space visionaries, dreamers and scientists had also envisioned orbiting satellites that could observe and report on weather phenomena from space. Although military officials had long recognized the importance of weather data for military operations, they often remained unable to gather needed information with conventional weather equipment over land and sea controlled by the enemy during conflicts and normally inaccessible during peacetime. Moreover, significant weather conditions frequently originated over water, where total coverage proved lacking, and spotty reports from ships or aircraft remained inadequate. In the aftermath of the Second World War, military authorities recognized the potential for weather reporting offered by "earth-circling" artificial satellites. As the 1946 Rand report predicted, "the observation of weather conditions over enemy territory" represented a most important kind of satellite observation.[24]

By 1961, the Air Force, largely through the Aerospace Corporation, studied the requirements for military weather satellites. Such satellites could provide photographs of cloud characteristics and their distribution for flight planning. Yet what appeared below the cloud cover, along with atmospheric temperatures, pressures, and wind velocities and directions, usually remained less susceptible to satellite measurements. At the same time, too much photographic information might saturate data processessing capability. Satellites might provide the perfect solution to these challenges, but only if scientists and engineers could develop capable sensors and supporting equipment.[25]

If technical problems presented military planners with one dilemma, civilian satellite operations already underway created another. NASA had received authority to develop weather satellites for all government users. It led the way with the low-altitude Television and Infra-Red Observing Satellite (TIROS) for the Weather Bureau. The successful launch of the 273-pound *TIROS I* by a Thor-Able II booster on 1 April 1960 from Cape Canaveral, Florida, opened a new era in meteorology.

Operating for only three months, it completed 1,302 orbits and transmitted nearly 23,000 photographs of global cloud cover from its position 450 miles in space. While *TIROS I* was establishing the feasibility of satellites for global weather observations, officials from the Departments of Defense and Commerce and from NASA met to consider development of a single weather satellite system that could satisfy the needs of both the military and civilian communities. Such a program would require civilian management to accord with the national policy of the peaceful use of space. After agreeing in principle, the Panel on Operational Meteorological Satellites by April 1961 had developed a plan for a low-altitude spacecraft termed the National Operational Meteorological Satellite System (NOMSS). But the NOMSS did not satisfy military requirements for coverage, readout locations, timeliness, operational flexibility, and security. Specifically, TIROS did not provide coverage of high-latitude and polar regions, while the satellites' cameras pointed to the earth little more than twenty-five percent of the time and observed specific earth areas at different times every day. Moreover, data transmission and processing weaknesses could not allow rapid operational data use. Reminiscent of the communications satellite issue, the Defense Department worried that political leaders, who viewed the weather satellite program as an example of the nation's peaceful space and foreign policies, might not allow such satellites to be available for military use in times of international tension. Although Nimbus, the second-generation weather satellite developed by NASA and the National Oceanic and Atmospheric Administration, improved upon many TIROS deficiencies, it proved to be a large, three-axis stabilized spacecraft that the space agency relegated to research use.[26]

As a result of these problems, early in 1963 the Aerospace Corporation recommended that the Air Force develop a dedicated military system, and the Defense Department agreed. The main emphasis would be on cloud-cover photography, but planners expected to add more sophisticated equipment when it became available. Later, when civilian weather satellites improved their capabilities and could satisfy most military requirements, the Defense Department continued to prefer a separate system responsive to the "dynamic" needs of the military. As a result, the Air Force embarked on the first segment of what became known initially as the Defense Satellite Applications Program (DSAP), or Program 417. Because the Air Force weather satellite program began with the mission of providing specific weather data to support Strategic Air Command and National Reconnaissance Office (NRO) requirements, the project remained classified until 17 April 1973, when Secretary of the Air Force Dr. John L. McLucas decided that the Defense Department's decision to use satellite weather data in the Vietnam conflict and to provide it to both the Commerce Department and the general scientific community warranted declassification of the DSAP mission and release of some of its performance data. In December 1973 the Defense Department changed the name to the Defense Meteorological Satellite Program (DMSP).[27]

The initial DSAP military weather satellites of the 1960s were relatively inexpensive and unsophisticated. Weighing 430 pounds and measuring approximately five feet in height and five feet in diameter, the twelve-sided spacecraft produced daytime visual and nighttime infrared weather photographs with resolution of one-third and two nautical miles, respectively. From polar, sun-synchronous orbit, two satellites transmitted weather data both early in the morning and at noontime to readout stations in Washington state and Maine, and from there to the Air Force's Global Weather Central facility at Offutt Air Force Base, Nebraska. Along with furnishing tactical weather information to Vietnam mission planners, the satellites passed auroral data to the Air Force's Cambridge Research Laboratory and the National Oceanic and Atmospheric Administration.[28]

By the early 1970s, the Air Force had launched four series of military weather satellites, each more capable than its predecessor. By the middle of the decade the Air Force prepared to launch the first of its fifth block of DMSP satellites with the Thor-Burner II booster pairing. This new generation of polar orbiting satellites, known as Block 5D, represented a major technological leap over previous models. Weighing 1,140 pounds and measuring four feet in diameter and twenty feet long, they tripled the size of the earlier satellites. Designed to provide both day and nighttime very high quality weather pictures, they also contained three times the number of special sensors. Most important among the latter proved to be an upgraded Operational Linescan System (OLS) to provide cloud-pattern images. A new integrated design that combined the satellite and upper stage of the booster created substantial weight savings. This made possible the use of redundant components which would increase the operational lifetime of the satellite from nine to as many as twenty-four months.[29]

Along with major advances in satellite capability came increased complexity, and problems with satellite stabilization and other technical difficulties led to questions about the system's reliability, its higher costs, and predictable scheduling delays. During the 1970s, DMSP also would face critics who sought to cut costs by combining the two parallel low-altitude weather satellite systems. As with the communications satellite issue, Defense Department officials relied on much the same argument to successfully withstand the pressure. To better retain a dedicated weather satellite system, the Air Force in 1973 sought, and achieved, active Navy and Army participation. After four years of discussion among the services, DMSP became a tri-service program.[30]

Despite developmental problems, no one could doubt DMSP's important contributions to military operations. The success of the initial program convinced officials to broaden the satellites' SAC-oriented mission to include tactical weather support. Their confidence proved justified when, in the late 1960s, planners in Vietnam relied extensively on DMSP data for conducting combat operations, while others counted on weather satellite data to provide accurate hurricane warnings and perform Apollo recovery operations in the Pacific Ocean. By the early 1970s, weather satellites reached the level of performance predicted for them a quarter of a century earlier.

The Quest for Precise Location—From Transit to Navstar/Global Positioning System (GPS). Navigation satellites represent a third major functional area of space applications that came of age by the early 1970s. Throughout history, one's location on the earth and the ability to navigate from one point to another have remained essential requirements. For the military commander, whether in the air, at sea, or on land, there can be no more important questions requiring answers than: where am I and where am I going on the route selected? Early navigation involved simple pilotage, the process of determining position using observable landmarks to move from point to point. Ancient mariners also used the positions of the sun, moon, planets, and stars as reference points and developed instruments such as the astrolabe and quadrant to provide basic measurements in latitude. Celestial navigation became increasingly accurate once the chronometer appeared in the eighteenth century to calculate longitude. Since that time improvements in sextants, compasses and other instruments have enabled aircraft and ships to determine their positions on the globe within a mile through celestial navigation. But mariners needed an answer to the dilemma of cloud cover and dense fog that often made celestial navigation impossible.[31]

The answer came in the 1920s with the development of radio, which led to various techniques of radio navigation, first based on using a radio receiver with a simple loop antenna to calculate the radio signal's direction and relative bearing to the transmitter. Later, experimenters relied on the difference in time of arrival of a signal from two correlated stations. Position is determined by the intersection of two hyperbolas produced by the time differences in arrival of the signal at the receiver. One of the most effective hyperbolic systems appeared early in the Second World War, when MIT's Radiation Laboratory developed LORAN (long range navigation), which used synchronized pairs of transmitters at different locations to produce measurable time differences for aircraft at great distances from the transmitter. Accuracy could reach approximately a fifth of a mile at a range of 1,000 miles. But LORAN and similar radio navigation techniques were two-dimensional systems, designed to determine latitude and longitude only, not altitude or velocity of the aircraft. Moreover, weather disturbances and ionospheric conditions made low-frequency radio waves subject to errors, while high frequency transmissions depended on line-of-sight capabilities and the synchronization of ground stations. Artificial earth-circling satellites, on the other hand, could provide ideal platforms for radio navigation transmitters.

On 13 April 1960, an Air Force Thor-Ablestar launched from Cape Canaveral, placed a 120-pound Navy *Transit IB* satellite into a 700-mile altitude, circular polar orbit, thereby making the Transit navigation system the first to use radio transmission from satellites. It proved to be a simple, reliable two-dimensional system based on Doppler measurements. Scientists from the Johns Hopkins Applied Physics Laboratory (APL) had discovered that measuring the Doppler shift in frequency of Sputnik's continuous-wave transmitter provided sufficient data for determining the complete orbit of the satellite. Conversely, knowing such satellite information, termed its ephemeris or almanac, one could establish precise positions on Earth using the same Doppler calculations. Transit satellites provided position accuracy to about 600 feet, which met the Navy's need for accurate location of slow-moving ships and ballistic missile submarines. But the Transit system proved too slow and intermittent—and two-dimensional—to satisfy the more demanding requirements for precise positioning of high-speed aircraft and ground-launched cruise and ballistic missiles.[32]

The answer would prove to be the Global Positioning System (GPS), which would improve the Transit approach and supply a three-dimensional system to provide position, velocity, and altitude by a process closely related to the LORAN technique for measuring time differentials. The initial concept for a modified LORAN-type system involving altitude together with latitude and longitude appeared in a 1960 study prepared by Raytheon Company scientists to support a mobile version of the Minuteman intercontinental ballistic missile (ICBM) force. As described by one of its creators, Ivan A. Getting, the new system, called MOSAIC (Mobile System for Accurate ICBM Control), "used four 3000-MHz (S-band) continuous-wave transmitters at somewhat different frequencies, with their modulation all locked to atomic clocks and synchronized through communications links."[33] When Getting left Raytheon to become the first president of the Air Force's nonprofit Aerospace Corporation, he supported further research on this concept and the challenges associated with a satellite navigation system applicable for tactical aircraft and other vehicles moving rapidly in three dimensions.

By 1963 the Aerospace Corporation's engineers and scientists convinced the Air Force that the path to accurate measurement lay in calculating distances to satellites with known positions. That October the Air Force charged the corporation to pursue its satellite ranging study, now termed Project 621B (Satellite System for Precise Navigation), with support from Air Force Systems Command's Space Systems Division in nearby Inglewood. From the start such a system would include the capability of supplying accurate, all-weather position data to an unlimited number of users anywhere on or near the surface of the earth. Planners believed they could achieve position accuracies within fifty feet in three dimensions (latitude, longitude, and altitude). At the same time, the system had to be cost-effective. By mid-1966 successful studies of this satellite navigation concept led the Air Force to award study contracts for system hardware design to Hughes Aircraft Company and TRW Systems. From 1967 to 1969 additional studies envisioned a global network of twenty satellites in synchronous, inclined orbits using atomic clocks synchronized with a master system clock. The ground tracks of the satellites would comprise four oval-shaped clusters extending thirty degrees on either side of the equator. Because the satellites would be placed in orbit periodically during the development phase, the system could achieve a limited operational capability well before the entire system deployed.[34]

Meanwhile, the Air Force work stimulated the Navy to continue its own advanced navigation research. In the mid-1960s Roger Easton of the Naval Research Laboratory developed a system he called Timation, for Time Navigation, based on using precise atomic clocks. In 1967 and 1969 the Air Force launched Navy Timation satellites carrying sophisticated crystal oscillators and rubidium atomic clocks, which transmitted UHF signals for ranging and time transfer. By 1971 the Navy and RCA, its main contractor, proposed a system of 21 to 27 satellites in inclined eight-hour orbits. Earlier the Army had proposed its own system called SECOR (Sequential Correlation of Range). In 1968 the Defense Department organized a tri-service committee, later called NAVSEG (Navigation Satellite Executive Committee), to coordinate the various projects.[35]

Tests of operator equipment at White Sands Proving Ground in 1971 and 1972 using ground and balloon-carried transmitters achieved accuracies within fifty feet. Yet the Defense Department proved reluctant to approve full development of the expensive, technically ambitions Air Force system. In late 1972 the satellite navigation program received a new leader, Colonel Bradford W. Parkinson, who opened talks with the Navy to combine the Air Force's Program 621B and the Navy's Timation. On 17 April 1973 William P. Clements, Deputy Secretary of Defense, called for a joint development program, termed Defense Navigation Satellite Development Program, with the Air Force acting as executive agent. By September 1973 a unified program adopted the Air Force signal structure and frequencies and the Navy's satellite orbits. The satellite orbits would be raised to 7,500 miles altitude to produce twelve rather than eight-hour periods. The system would also use atomic clocks, which the Navy had already successfully tested in its Timation program. By December, Secretary Clements had authorized the first in a three-phase development effort. The initial four-year period comprised a four-satellite configuration in 10,500 NM twelve-hour orbits to validate the concept. On 2 May 1974 the Air Force renamed the planned system the Navstar Global Positioning System (GPS).[36]

In the coming years, GPS development would be beset by critics who worried about the vulnerability of the satellites, the susceptibility of the receivers to jamming, or the possibility of an enemy using the system to its own advantage. The global economic recession of the 1970s also made it difficult to obtain Defense Department funding that seemed more available for weapon systems than for defense support systems. Even so, by the early 1970s the Air Force found itself playing the key role in the creation of a space applications program that, if successful, promised to revolutionize the tactical battlefield.

Surveillance from Space—From Vela Hotel and the Missile Defense Alarm System (MIDAS) to the Defense Support Program (DSP). In many ways, surveillance from space for missile detection and early warning represents the most important space-application function in the military space program. By the early 1960s the outlook for space reconnaissance proved immensely successful. On the international level, all nations came to accept the principle of "open skies" with right of overflight through space, while negotiations between the United States and Soviet Union produced international agreements prohibiting weapons of mass destruction in outer space. On the technical level, engineers and scientists demonstrated that satellites in synchronous equatorial orbit would remain above the same point of land, because the earth rotates beneath the satellite at the same rate as the satellite travels in its orbit. With the advent of solid-state microelectronics, satellites could collect vast amounts of data by means of increasingly powerful sensors, and rapidly transmit to ground receiving stations information that could be made available to a global network of users in near-real time. By the early 1970s such operations would become increasingly routine.[37]

Space reconnaissance involved the so-called "black world" of highly classified national space programs that, since 1961, were outside the purview of direct Air Force management responsibility. When the Defense Department terminated the Air Force Samos reconnaissance satellite program in 1962, it left the space reconnaissance field to the increasingly successful, CIA-Air Force CORONA project under the National Reconnaissance Office (NRO). Although the Air Force furnished personnel, boosters, and infrastructure support for the CORONA effort, the highly classified project continued as a national reconnaissance effort, outside mainstream Air Force space activities.[38] The Air Force, however, directed and managed two other important space surveillance satellite programs. MIDAS, or Program 461, involved developing an effective early warning satellite to detect the launch of ballistic rockets using infrared radiometers. The other, Vela Hotel, comprised a space-based system to detect nuclear/thermonuclear detonations in the atmosphere and outer space. It provided the "space watch" necessary to ensure compliance with the limited nuclear test ban treaty of 1963 and supported a variety of disarmament initiatives. In effect, it became a crucial element of the "national technical means" for verifying compliance with nuclear weapons agreements.[39]

The perceptive Project Rand report of 1946, which considered the military applications for surveillance satellites, called attention to "the spotting of points of impact of bombs launched by us [the United States] as one major type of observations provided by satellites."[40] The Vela program altered this prediction by directing sensor attention to nuclear detonations in space in all locations. Serious efforts to develop a satellite capability to monitor high-altitude nuclear tests date from international conferences at Geneva in 1958 and 1959, followed by congressional hearings in April 1960. These discussions prompted ARPA to develop the Vela program to detect all types of nuclear testing. The Atomic Energy Commission (AEC) and the Defense Department, through ARPA, managed the program jointly. Vela comprised three segments. Vela Uniform focused on underground or surface nuclear detonations using seismic techniques, while Vela Sierra involved ground-based detection of nuclear explosions above the earth's surface. Vela Hotel, the third element, served as the "watchman" for space-based detection of nuclear bursts in the atmosphere and outer space. Vela Hotel's challenge from the start was to be able to discriminate between nuclear detonations and natural background solar or cosmic radiation.[41]

Under ARPA's direction the Air Force became responsible for providing Vela Hotel the boosters and spacecraft. The Atomic Energy Commission laboratories furnished the instrumentation and Lawrence Radiation Laboratory the sensors. On 22 June 1961 ARPA authorized a test program of five Discoverer/Project CORONA Atlas/Agena launches of two Vela spacecraft each at three-month intervals. Planners scheduled the initial launch for April 1963. Vela proved to be an exceptionally well-managed program, and only twenty-eight months elapsed between program approval and data received from Vela Hotel sensors. Built by TRW, the spacecraft themselves measured 58 inches in diameter and weighed about 500 pounds. The intriguing Vela shape, an icosahedron, consisted of a solid with twenty equilateral-triangle faces and twelve vertices to allow X-ray detectors to view more than half a hemisphere. Other detectors appeared at the vertices and inside the spin-stabilized satellite. Orbiting at 60,000 miles altitude and spaced 140 degrees apart, the spacecraft's powerful four-watt transmitter sent 256 data bits per second to sixty-foot ground antennas by means of dipole antennas. In addition to its main function, additional instruments determined background radiation levels and fluorescence produced by nuclear blasts.[42]

Not surprisingly, the Vela "treaty monitors" made their initial appearance shortly after the United States ratified the Limited Nuclear Test Ban Treaty. On 16 October 1963, an Atlas-Agena B lifted the first two Vela satellites into a 67,000-mile circular orbit at thirty-eight-degrees inclination. A second pair followed on 17 July 1964 and a third the following year. The launch success and on-orbit reliability of the first six satellites convinced planners to cancel the final two launches and modify the fourth and fifth pairs for atmospheric surveillance. Expected only to remain operational for six months, the initial Vela satellites operated for a period of five years. The fourth and fifth earth-oriented pairs became operational in 1969 and 1970 and functioned superbly, well beyond their predicted eighteen-month lifespans. To the relief of all involved in the program, the sun's X-ray bursts did not produce an excessive number of unrecognizable false alarms in the Vela sensors.[43]

So successful was the program that the Air Force in 1965 turned Vela over to TRW, which became responsible for all future work. The contractor developed larger and more sophisticated satellites, with the last pair, the eleventh and twelfth in the series, launched in 1970. The Vela program demonstrated that a complex system could be developed and successfully deployed in a period of only five years, then turned over to contractor management for an additional five years of "routine" operations. In the 1970s Vela satellites gave way to nuclear detectors placed on other Air Force satellites. As part of a defense policy "of launching fewer but larger spacecraft and using them for multiple functions," officials redesignated the nuclear detection system the Integrated Operational Nuclear Detonation Detection System (IONDS), and in the 1970s sent detectors into space aboard Defense Support Program early warning and GPS navigation satellites.[44]

The Defense Support Program (DSP) succeeded the MIDAS missile detection and early warning space watch program in the late 1960s. Unlike Vela Hotel, MIDAS experienced problems from its inception. MIDAS relied on advanced electronic and cryogenic technology to move beyond the visual spectrum to the spectrum of much longer infrared wavelengths. By recording heat emissions from objects on Earth, infrared radiometers in aircraft could produce thermal pictures during darkness and identify camouflaged targets. MIDAS envisioned using polar-orbiting Agena satellites with infrared scanners mounted on a rotating turret that scanned the earth continuously to detect ICBM exhaust flames within moments of their launch. Initially, planners expected to launch MIDAS satellites into polar orbits at 300 miles altitude, but the high-intensity background radiation from sunlit clouds and other phenomena convinced officials to raise the altitude to 2,000 miles. Even so, the challenges remained formidable.[45]

The MIDAS story illustrates a number of complexities faced by Air Force space planners determined to develop a much-needed but technologically challenging system during the McNamara era. Where, for example, was the balance between keeping a program in the study phase, or the development phase, before deploying it as an operational system? Where was the point beyond which the value of the data produced by the system failed to justify the high cost of its development, deployment, and operation? How did the Air Force achieve the proper booster-payload combination during the advance of technology and changing satellite mission requirements? The approaches to these questions normally found the Air Force operational commands favoring early operational capability for MIDAS and, as a result of early failure, the Defense Department preferring a more deliberate, research-oriented focus. As a result, MIDAS experienced a rocky development road, often appearing to end in premature cancellation of the project. Nevertheless, MIDAS established the groundwork for its incredibly successful successor, DSP, which would become the central component in the nation's global missile warning network.

When the Kennedy administration took office in early 1961 MIDAS already faced major survival hurdles. During the reorganization of the satellite reconnaissance program in August 1960, MIDAS' technical difficulties convinced Defense Department officials to reemphasize technical development. Air Force leaders, concerned about the growing Soviet ICBM threat, lobbied hard for an early operational date for the infrared detection system. That fall General Laurence S. Kuter, the commander-in-chief of the North American Air Defense Command (NORAD), and the commander of the Air Force's Air Defense Command (ADC), Lieutenant General J. H. Atkinson, urged Chief of Staff General Thomas White to authorize an expedited and expanded MIDAS development program. If the Joint Chiefs of Staff were to approve the preliminary MIDAS operational proposal of February 1960, which had raised the ire of Army and Navy representatives, NORAD would receive operational control and ADC designation as the "using Air Force command." General White reminded the commanders that not only the operational plan awaited action by the Joint Chiefs of Staff, but the basic MIDAS development plan had yet to receive Defense Department approval. He convinced DDR&E chief Herbert York to authorize two radiometric tests aboard upcoming Discoverer/Project CORONA flights. The planners hoped that these experiments could answer the basic question surrounding the future of MIDAS: could the infrared detectors distinguish between missile radiation in the boost phase and high-intensity natural background radiation? Meanwhile, in September 1960, Dr. W. K. H. Panofsky of Stanford University headed a panel of the President's Scientific Advisory Committee, which concluded that the MIDAS concept remained sound and that every effort should be pursued to overcome engineering problems and produce an operational system by 1963.[46]

Early in 1961, following a considerable number of program revisions, planners at Air Force Systems Command's Ballistic Missile Division continued work on a "final" development plan that excluded any reference to operational funding or capabilities in favor of concentration on research and development. This dichotomy pitted Air Force commands, including Air Defense Command, that favored accelerated satellite development and early deployment against the Air Force research and development community and an Office of the Secretary of Defense whose worries about technical feasibility and high costs led them to favor a more cautious approach. It would characterize the course of MIDAS development throughout the 1960s. The "final" MIDAS development plan appeared on 31 March 1961. It scheduled twenty-seven development launches rather than the twenty-four proposed earlier, with initial operational capability set for January 1964. Meanwhile, the Joint Chiefs of Staff and Secretary of Defense on 16 January 1961 approved the operational plan that assigned MIDAS responsibilities to NORAD and the Air Defense Command. In mid-March Air Defense Comand authored a proposed operational plan calling for a constellation of eight satellites spaced in two orbital rings to ensure continual coverage of the Soviet landmass. Data from the sensors would be transmitted to Ballistic Missile Early Warning System (BMEWS) radar sites, then relayed to the NORAD command post. Planners hoped to achieve a twenty-four month satellite lifespan, but by mid-June 1961 Under Secretary of the Air Force Joseph Charyk balked at authorizing an operational configuration without additional infrared sensor data from forthcoming flights. Operational and logistic planning priorities gave way to emphasis on demonstrating acceptable early warning techniques.[47]

During the summer of 1961, Harold Brown, the Kennedy administration's new DDR&E chief, conducted an extensive review of the MIDAS program for Secretary of Defense McNamara. He predicted that, ultimately, engineers could solve severe problems associated with system reliability and the detection of both low- and high-radiance missile emissions, but he raised doubts about the system's ability to detect small, Soviet Minuteman- and Polaris-type solid-fuel missiles. He estimated the warning time for a potential high-radiance liquid-propellant ICBM attack at five to twenty minutes. Was the additional warning time worth the effort required to solve the technical problems and the estimated $1 billion price tag for operational capability, not to mention the $200 million needed for annual operations? At this time Secretary McNamara was reassessing the broader concept of how the country should respond to an enemy attack. If the nation's leaders chose not to retaliate on warning of a missile assault, but to rely primarily on the ICBM second-strike capability, the additional strike aircraft made available by a MIDAS alert would prove of little value. Not surprisingly, the Air Force vigorously countered by showing that ten minutes of additional warning time would guarantee that fourteen percent of the Strategic Air Command bomber force could become airborne, while fourteen minutes would raise this figure to sixty-six percent.[48]

The technical and political uncertainties, along with Air Force criticism, compelled Brown that summer to appoint a study group headed by John Ruina, to examine the issues of MIDAS technical capabilities and mission importance. Although the Air Force considered the Ruina study just one more in a long line of investigations that had delayed MIDAS development, General Schriever went to the heart of the matter when in the fall of 1961 he wrote Air Force Chief of Staff General Curtis E. LeMay that "complete satisfaction can only be achieved by a conclusive demonstration of system feasibility through an orbital flight test that detects and reports the launch of ballistic missiles and has a reasonable orbital life." Such capability appeared far in the future. MIDAS experimental flights occurred as part of Project Discoverer/CORONA. The first two flights, on 26 February and 24 May 1960, produced little significant data. The first launch failed after an explosion occurred upon separation of the second-stage Agena from the Atlas booster, while *MIDAS 2*'s sensors operated successfully for two days from its 300-mile-high orbit before its communications link failed. The third MIDAS spacecraft, launched on 12 July 1961, returned data from its experimental infrared telescope for only five orbits before failure of the solar array auxiliary power. Although *MIDAS 4* successfully achieved a near circular polar orbit at a 2,200 nautical mile altitude, on 21 October 1961, it operated for only seven days without meeting any of the flight's objectives.[49]

Even before the Ruina group issued its report, the Office of the Secretary of Defense deleted all fiscal year 1963 MIDAS nondevelopmental funds and refused to sanction an operational system. The Ruina report deepened a mood of doom and gloom. Issued on 30 November 1961, it faulted the current MIDAS design as too complex for reliable use, expressed skepticism regarding the system's ability to detect solid-propellant missiles, and criticized the Air Force for focusing on immediate operational capability to the detriment of essential research and development. The report recommended a major reassessment to produce a simplified MIDAS with more attention directed to research and development. In December Brown directed the Air Force to implement the group's findings. Referring to the report's "serious allegations," General LeMay reacted sharply by requesting several alternate development proposals and by working to defer the DDR&E directive. Air Force Systems Command's Space Systems Division moved quickly to form an advisory group under Clark Millikan of Cal Tech to assess the Ruina report. The Millikan group faulted the Ruina panel for being unaware of the scope of available test data, and for erroneously analyzing the cloud-background-clutter data in assessing the infrared sensor's capability. A simplified system, the group asserted, could be operational before 1966.[50]

Of the various plans Air Force Systems Command prepared, the most convincing one stressed research and development and more test flights. During February and March 1962 Air Staff members repeatedly met with DDR&E officials to convince them to accept the Air Force proposal, which Space Systems Division completed on 29 March 1962. It called for as many flights as possible leading to an initial operational capability between mid-1965 and mid-1966. It also projected a fiscal year 1962-1963 budget increase from the programmed $290 million to $334 million. Then, on 9 April 1962, the Air Force finally found itself in a position to break the logjam on MIDAS development. On that date a fifth MIDAS flight achieved polar orbit and began transmitting data which demonstrated that it could discriminate between cloud background and rocket exhaust plumes. The very next day Air Force Assistant Secretary Brockway McMillan requested that DDR&E approve the 29 March plan. In response, Brown released funds to sustain the program through the fiscal year, but he declined to authorize development.

In fact, the DDR&E chief sponsored another review of MIDAS. This time Stanford's Panofsky reappeared to chair another panel. Unlike his favorable 1960 conclusion, this time he agreed with the Ruina panel's findings and criticized the Air Force for proposing operational prototype flights when basic missile detection capability remained in doubt. Harold Brown notified the Air Force that he would not release further funds until MIDAS proved capable of detecting low-radiance missiles. While unhappy Air Force officials prepared yet another plan—one involving an accelerated research schedule—to accommodate DDR&E concerns Secretary McNamara told Air Force Secretary Zuckert that the Defense Department would conduct a "full-scale" analysis of MIDAS in light of the importance of early warning and the seriousness of the Soviet ICBM threat. At the same time, Brown criticized the Air Force for focusing on an early operational capability without first solving basic questions about low-radiance, noise background, and system reliability. By the summer of 1962, MIDAS supporters had little reason for optimism, and in early August, Secretary McNamara announced reduction of MIDAS to a limited research and development program because of its expected slow development, high costs, available early warning alternatives, and the decreased value of early warning occasioned by the growing importance of hardened missile sites compared to the strategic bomber force. The Defense Department subsequently cut funding for fiscal year 1963 to $75 million and for fiscal year 1964 to $35 million.[51]

By the spring of 1963 it appeared that MIDAS might be doomed to extinction as another system too ambitious technologically to warrant operational development. Then, in May 1963, the fortunes of MIDAS seemed to make an abrupt recovery along the lines forecast by General Schriever two years earlier. On 9 May an Atlas-Agena launched Flight Test Vehicle 1206 from Vandenberg Air Force Base into a near-perfect 2,000-mile-altitude circular orbit. Over the next six weeks, the satellite vindicated its supporters by detecting nine launches of solid-propellant Minuteman and Polaris as well as liquid-propellant Atlas and Titan missiles. A subsequent flight on 18 July confirmed "real time" detection of an Atlas E launch as well as the ability to monitor Soviet missile activity. Above all, the flights convinced officials that MIDAS could provide real-time data on missile launches without interference from earth background "noise." The successful flights prompted Secretary McNamara to reevaluate the possibilities for tactical warning and the future of MIDAS.[52]

Although at this time Air Force Systems Command responded with four alternative proposals designed to achieve an operational system, the Air Staff adopted a more flexible response that called for a prototype approach on the assumption that neither current technology nor funding constraints warranted an entirely operational system. The Air Staff Board recommended that Air Force Systems Command improve system tracking and launch site identification techniques as well as the real-time detection of low-radiance, short-burning solid-fuel missiles, and that it consider additional defense applications. Most interesting, the Air Staff, in the name of cost-effectiveness, favored the development of more simplified, more reliable satellites with longer orbital lifespans; such satellites also would orbit at higher altitudes to provide greater coverage of the earth with fewer spacecraft. On 1 October 1963 the Chief of Staff approved a three-phase flight test program extending throughout the remainder of the decade with initial fiscal year 1965 funding set at $100 million.[53]

In early November 1963, Brown suggested that Program 461 be reoriented to include detection capability of submarine-launched ballistic missiles (SLBMs) and medium-range ballistic missiles (MRBMs), while later in the month the Office of the Secretary of Defense cut the Air Force proposed fiscal year 1965 figure of $100 million to $10 million. In early 1964 Brown agreed to release only half of the fiscal year 1964 MIDAS budget allocation, explaining that the "drastic reduction" resulted from alternative early warning systems and anticipated high deployment costs for MIDAS. Nevertheless, he agreed the recent flight successes warranted continuing the program, but with four objectives beyond its initial strategic warning function. His list included reliability, global coverage, launch point determination, and real-time detection of nuclear detonations as well as SLBM and MRBM launches. If the Air Force reoriented the program according to his guidelines, MIDAS could expect increased funding support in future. The latest modification of the MIDAS effort, the DDR&E chief admitted, envisioned a major deviation from a system originally designed to detect a mass raid of Soviet missiles.[54]

Given the budget cutback, the Air Force remained concerned about the program's future. Already scheduled flights would have to be canceled resulting in termination of contracts, substantial investment losses, and a four-year hiatus between the series of radiometric and system detection flights. Throughout the spring of 1964, Air Force officials negotiated with DDR&E to reach an acceptable compromise. By late spring the Air Staff proposed a minimal program designed to preserve both near- and long-term objectives by the increasingly prevalent method of slipping the flight schedule and accepting greater technical risk.[55]

Budget cuts and skepticism within Defense Department circles continued to plague the infrared-detection satellite early warning program. In late 1964 and throughout 1965 the Defense Department's proposed fiscal year 1966 through 1969 budget reductions prompted major efforts by the Air Staff and Air Force Systems Command's Space Systems Division to keep MIDAS afloat without having it revert to development status. Their dilemma did not benefit from delays caused by Lockheed's difficulties with sensor components, a labor walkout at payload producer Aerojet General Corporationand launch site availability problems at Vandenberg Air Force Base. As revised, the MIDAS program in the latter half of the decade called for two phases of tests. Between 1966 and 1968, flights would conduct a variety of experiments in three stages at altitudes from 2,000 to 6,000 miles; in 1969 and 1970 more tests and a final operational assessment would occur with satellites launched by Titan IIICs to a 6,500-mile orbit.[56]

MIDAS remained a test program. Although Program 461 had shown conclusively that satellites could provide early warning of a missile attack by detecting and tracking missiles of all sizes, in the late 1960s mounting costs, low budgets, technical problems—and ambitious expectations—outpaced the original MIDAS program.

Moreover, with the advent of the Titan III booster, it became increasingly possible to contemplate launching larger, more capable infrared-detection satellites into geosynchronous orbits, where fewer satellites could cover more ocean and earth areas. As a result, DDR&E in August 1966 approved Program 949. Originally designed to monitor the Soviet Fractional Orbital Bombardment (FOB) threat, it soon came to be regarded as the replacement for ground-based warning systems such as BMEWS. As the MIDAS successor, it could ensure simultaneous warning of all three potential space and missile threats—ICBMs, FOBs, and SLBMs. In the spring of 1969 a breach in security eventually led officials to rename Program 949 the Defense Support Program (DSP).[57]

In November 1970, a Titan IIIC launched the first TRW-built DSP satellite into an elliptical, rather than the intended synchronous-altitude, orbit over the Indian Ocean. Referred to as "the best mistake we ever made," the spacecraft successfully transmitted data on American and Soviet launches to tracking stations as it circled the globe every five days. In April 1971 the newly completed overseas ground station at Woomera, Australia, took control of the satellite when in view, while at other times the Satellite Control Facility at Sunnyvale, California, assumed control. An additional ground tracking station at the Buckley Air National Guard Base near Denver, Colorado, joined the system in late 1972. By this time a second DSP satellite had been successfully lofted into synchronous orbit. In early 1973 a third early warning infrared satellite joined the constellation in synchronous equatorial orbit over the western hemisphere, where it helped monitor the SLBM threat from the Atlantic Ocean.[58]

DSP satellites represented a major technological leap over their MIDAS predecessors. Weighing 5,200 pounds, the DSP spacecraft measured thirty-three feet in length and nine feet across. Four solar panels covered one end of the cylinder-shaped satellite which housed the electronics. The other end housed a twelve-foot telescope with an array of 2,000 infrared detectors. In contrast to MIDAS, the DSP satellite itself rotated, at six revolutions per minute. Planners expected it to far exceed MIDAS in both coverage and reliability.[59]

In the months and years ahead, Air Force planners would worry about the challenge of developing DSP computer software which could receive and process an incredible amount of data then transmit the results almost instantaneously to users worldwide. They also remained apprehensive about loss of coverage due to adverse sensor angles over the pole and uncovered nadir holes, and they lobbied for additional satellites to provide redundant capability. Citing budget constraints in the 1970s, Defense Department officials proved unresponsive. They effectively noted the unexpected, outstanding performance achieved by the three-satellite network that immediately came to serve as the bedrock of early warning protection against the Soviet and "nth" country missile threats. With DSP performing space watch, a surprise attack became next to impossible.[60]

Ground-Based Space Surveillance Comes of Age

The Space Detection and Tracking System (SPADATS). SPADATS furnished additional protection against surprise attack by providing a space watch for detecting, tracking, and monitoring satellites and debris from low earth orbit to deep space through its network of ground-based sensors and control and data processing facilities. Operational responsibility for SPADATS had been a contentious issue between the Air Force and the Navy in the closing years of the Eisenhower era. On 7 November 1960 the Joint Chiefs of Staff acceded to Air Force wishes by assigning NORAD operational control and the Continental Air Defense Command (CONAD) operational command of SPADATS. In January 1961 the Secretary of Defense confirmed the decision, and the Air Force followed by making the Air Defense Command responsible for technical control of Spacetrack, the Air Force segment of the surveillance system. In mid-February 1961, the 1st Aerospace Surveillance and Control Squadron was activated to operate the new SPADATS data collection and catalog center as part of NORAD's Combined Operations Center at Ent Air Force Base, Colorado. The latter assumed the responsibilities previously handled by the Interim National Space Surveillance and Control Center (INSSCC) data filtering and cataloguing center at the Air Force's Cambridge Research Center in Massachusetts.[61]

The Air Force Spacetrack sensor network at that time included the Millstone Hill radar in Massachusetts, Baker-Nunn satellite tracking cameras, available observatory telescopes, and a variety of research and development and missile early warning radars. None of the equipment belonged to the Air Defense Command, and the performance of the detection, tracking, and cataloguing network suffered severely from accuracy, timeliness, and range weaknesses. On 1 February 1961 NORAD had assumed operational command of the Navy's Space Surveillance (Spasur) east-west minitrack radar fence and its data processing facility in Dahlgren, Virginia. During the acceptance ceremonies, NORAD Commander-in-Chief General Laurence J. Kuter observed that with thirty-two American and three Soviet spacecraft in orbit, the need for a constant, accurate space watch had arrived.[62]

Over the next few years NORAD, CONAD, and ADC worked diligently to expand system capabilities through computerized "volumetric" track-and-scan sensors to provide immediate detection and identification of multiple space objects. At the same time, they also labored to expand their area of operational and ownership responsibility. By 1965 the ADC's Spacetrack Operations Center at Ent Air Force Base received data from assigned detection fan and tracking radars at Shemya, Alaska, and Diyarbakir, Turkey. The new Shemya FPS-80 tracking radar, for example, proved capable of detecting within minutes Soviet satellites launched from Kapustin Yar and providing highly accurate satellite positioning data to a distance of 2,500 miles. The previous year, ADC had accepted AFSC's FPS-49 long-range pulse Doppler tracking radar at Moorestown, New Jersey, and a scanning radar and 84-foot dish tracking radar at Trinidad, British West Indies. Although hampered by azimuth and elevation restrictions, the Trinidad tracker could follow one-meter-square targets at 2,000 miles, and the site proved especially important in detecting and tracking Soviet satellites in low-inclination orbits.[63]

Spacetrack also relied on a network of Baker-Nunn cameras at Oslo, Norway; Edwards Air Force Base, California; and Sand Island in the Pacific for deep-space surveillance. Far superior to electronic sensors of the time, the optical cameras could record one-meter-square targets to a range of 50,000 nautical miles, provided the camera operated in twilight or darkness, free of clouds, against illuminated targets. Data readout delays put the Baker-Nunn cameras in the category of contributory systems. In addition, the Ballistic Missile Early Warning System (BMEWS) radars at Thule, Greenland; Clear, Alaska; and Fylingdales, England, represented a supplementary Spacetrack component. The Air Force also had under development an FSR-2 prototype electro-optical satellite sensor at Cloudcroft, New Mexico, and a new FPS-85 phased array radar at Eglin Air Force Base, Florida. Both sensors, however, could not meet their programmed 1965 initial operational dates. The Cloudcroft radar experienced technical problems that prevented it from joining Spacetrack immediately, while a fire in January destroyed seventy-five percent of the Eglin radar and delayed its completion until 1967.[64]

Spasur and Spacetrack underwent continual improvements in their capabilities to detect, track, and monitor a space population that by 1969 found NORAD's Space Defense Center in Cheyenne Mountain observing 20,000 objects daily. By the early 1970s the Air Force and NORAD exercised responsibility for nearly the entire SPADATS sensor and control system, and they planned to monitor objects in deep space by replacing the Baker-Nunn network with the Ground-based Electro-Optical Deep Space Surveillance (GEODSS) System. The latter would include three optical telescopes supported by sophisticated computer software and processing and display equipment. Like other space systems, by the 1970s the growth in sophisticated sensors and supporting equipment served to make Spacetrack and SPADATS increasingly responsive to operational requirements.[65]

A Fleet of Space Vehicles Sets the Course

While orbiting satellites increasingly provided important space-based information for larger numbers of operational commanders and other users, their performance remained dependent upon boosters and upper-stage vehicles capable of placing them in the desired orbits. Available space boosters had enabled the Air Force to achieve early space supremacy among the services, and the responsibility it received as the "booster service" guaranteed its central space role throughout the 1960s.

Before 1960, ARPA, NASA, and the Army and Navy carried out all but two of the American space launches. In 1960, the Air Force began its dominance of the space launch business with fourteen of the twenty-nine service-sponsored flights that year, and the trend would continue. When the Air Force initiated its space program it had a ready-made advantage in the liquid-propellant ballistic missile force designed and built in the 1950s. The Thor IRBM and Atlas ICBM could not compete favorably with their heavier Soviet counterparts and soon were superseded by the more capable solid-fuel Minuteman ICBM and Polaris SLBM. Nevertheless, the Thor and Atlas would continue to provide effective, reliable space boosters for a wide variety of unmanned space flights well into the era of the Space Shuttle.[66]

The Douglas Aircraft Company's Thor, measuring 65 feet in length and 8 feet in diameter, relied on liquid oxygen and kerosene to produce 150,000 pounds of thrust from its single main engine. It began its impressive flight history with the initial December 1959 Discoverer/Project CORONA launch and continued to operate primarily from the Western Test Range, at Vandenberg Air Force Base, where it launched in a southerly direction to achieve polar orbits. The more capable 71-foot-long, 10-foot-wide one-and-a-half-stage Atlas ICBM, built by General Dynamics-Astronautics, could produce at lift-off 387,000 pounds of thrust from its three main and two vernier engines. Atlas began its booster career by launching heavier payloads from the Eastern Test Range at Cape Canaveral. Both Thor and Atlas would remain workhorses for the Air Force for the remainder of the century. In the 1960s, the Air Force augmented its booster fleet with Martin-Marietta's Titan IIIC, consisting of a two-stage liquid-propellant rocket core with two enormous solid-propellant strap-on motors and a "Transtage." Measuring 108 feet long by 10 feet in diameter, this launch combination generated nearly 3,000,000 pounds of thrust and could place up to 33,400 pounds into low-earth orbit and nearly 4,000 pounds into a synchronous equatorial orbit. With the Titan, the Air Force possessed a booster of vastly increased size, capable of launching a wide range of satellites into higher-altitude orbits.[67]

For both Thor and Atlas and their heavy-lift successor, the Titan, upper-stage vehicles immediately became fundamental for mission success. Thor initially used Space Technology Laboratories' Able, a modified Vanguard vehicle, consisting of an solid upper stage and two liquid lower stages, and the improved two-stage Aerojet Able Star, whose liquid-propellant engine was restartable in space. The Thor booster became a favorite NASA launch vehicle for its own and foreign satellites when, in 1959, the civilian agency developed two more sophisticated solid-propellent Vanguard upper stages, and renamed the three-stage spacecraft Delta. The Air Force preferred to use the Agena, which Lockheed had begun developing in 1956. More than any other booster-satellite craft, the Agena "put the Air Force in space." Serving as a satellite once placed in orbit, the Agena went through several models, with the Agena B in use by the Air Force and NASA until 1966. Seeking a basic Agena upper-stage vehicle, Lockheed responded to an Air Force request by developing the standard, thirty-seven-foot-long and five-foot-wide Agena D. First launched atop of a Thor from the Western Test Range on 27 June 1962, the Agena D would continue to serve the Air Force into the early 1980s before the rocket-powered space glider, the Space Shuttle, became operational. The Agena D's common configuration included four usable modules containing the major guidance, beacon, power, and telemetry equipment, a standard payload console, and a rear rack above the engine for plug-in installation of optional gear-like solar panels, "piggyback" subsatellites, and an optional Bell Aerosystems engine that could be restarted in space as many as sixteen times.[68]

The Air Force's efforts to achieve standardization also embraced the stable of launch vehicles. It sought to emphasize similarities for the various missions while keeping deviations to a minimum. With a more powerful booster on the drawing board by 1961, Thor and Atlas became known as medium launch vehicles, with Thor designated SLV-2 (standard launch vehicle) and Atlas SLV-3. Although the small Scout booster received the designation SLV-1, it normally served NASA mission interests.[69]

The original single-stage Thor booster could support a variety of upper stages, such as Aerojet-General's Able and AbleStar, Lockheed's Agena A and B, and McDonnell Douglas' Delta. The standardized version included a Thor, modified with additional tankage and an upper-stage Agena D. It proved capable of launching 1700 pounds into a 115-mile circular orbit from Vandenberg Air Force Base, or just over 3,000 pounds from the Eastern Test Range. Later in the decade, a standard Thor with the addition of three strap-on Castor solid rockets, became the SLV-2A Thrust Augmented Thor with a 30-percent increase in payload capability. In 1966 a further modification took place by lengthening the Thor's propellant tanks. Known as the SLV-2H, this version demonstrated sixty-five seconds additional burning time and a 35-percent payload capability increase over the SLV-2A. Other versions included the Delta and Boeing Burner II upper stages. The Thor achieved a remarkable performance record that included only three failures among 154 launches from 1962 to 1972. In the 1970s the Air Force designated the Thor to launch the Defense Meteorological Satellite Program (DMSP) satellites.

The Atlas booster attained an equally enviable record of accomplishment. Initially, the Air Force used Atlas D missiles with slight modifications to accommodate the Agena upper-stage vehicle. In 1963 additional changes produced the Atlas SLV-3, while two years later the SLV-3A appeared with propellant tanks lengthened by twelve feet. Normally launched from the Eastern Test Range, it could place an Agena D payload of 8,600 pounds into a 115-mile low-earth orbit. The Atlas SLV-3D version used a Centaur upper stage for NASA launches, and in the early 1970s officials selected it to launch the Navy's Fleet Satellite Communications (FLTSATCOM) satellites. When the Minuteman intercontinental ballistic missile replaced the Atlas ICBM in the mid-1960s, the Air Force determined that savings could result by refurbishing Atlas missiles from silos in the midwest rather than purchasing new SLV-3s. Redesignated the Atlas E and F, these "wheatfield" boosters proved highly reliable from 1967 to 1979 in support of Air Force research experiments as well as

TIROS and Global Positioning System launches. Atlas also served as the basic booster for NASA's Mercury program.[70]

With the first successful launch of a Titan IIIC on 18 June 1965, the Air Force had a booster sufficiently powerful to launch satellites into geosynchronous orbit. The following year a Titan IIIC successfully launched the first series of IDCSP military communications satellites into a near synchronous orbit, 21,000 miles above the equator. In the 1960s and early 1970s, the Air Force developed two other versions of the Titan III. Originally designed for the manned orbiting laboratory, the Titan IIIB used a lengthened core to enable it to place an 8,200-pound payload into a 115-mile polar orbit when launched from the Western Test Range. By 1971 the Air Force had developed the Titan IIID, which added two five-segment solid rockets to the core but used a third-stage Agena in place of the Transtage. Intended as a transition to the Shuttle, it operated exclusively from the Western Test Range to place payloads weighing as much as 24,600 pounds into a 115-mile polar orbit. On 2 November 1971, it successfully launched the first pair of 1,200-pound DSCS II satellites into synchronous orbit.[71]

The success of the Titan III in the 1960s vindicated its proponents who sought to create a "DC-3 of the space age." During the period from 1964 through 1979, 111 of the 119 launches proved successful. Of these, six failures occurred with the Titan IIIC, primarily with the Transtage portion. While Air Force leaders like General Schriever bemoaned the micromanagement approach taken by the McNamara Defense Department, officials in the Office of the Seccretary of Defense could proudly point to the Titan's record of both launch and budget success. The total development cost of $1.06 billion proved well within estimates, considering inflation, two significant program changes, and a scheduled "stretch-out."[72]

By the 1970s, space launch vehicles had matured to the point where Air Force planners could consistently count on available standard Air Force boosters for launching substantial payloads, placing them into complex orbits, and demonstrating reliable performance. Nevertheless, with the advent of the reusable Space Shuttle, the future appeared uncertain for the Air Force's fleet of expendable space boosters.

Space Infrastructure Provides the Support

The integration of Air Force space systems also depended on the supporting infrastructure of booster launch centers, a tracking network and control center, and processing centers to evaluate and transmit data to users. In the late 1950s, the Air Force's Weapon System 117L and the many-faceted Project Discoverer/CORONA precipitated a major expansion of space infrastructure that continued unabated with NASA's rise in the 1960s.

Two major Air Force launch centers supported the nation's satellite program from its inception. One, the Eastern Test Range at Cape Canaveral, Florida, and renamed Cape Kennedy following the President's death, began in the late 1940s as a joint long-range proving ground run by the Air Force. Comprising the northernmost wedge of a barrier island fifty miles east of Orlando on the Florida coast, the Cape remained separated from the mainland to the west by the Banana River, Merritt Island, and the Indian River, which comprised a portion of the Intercoastal Waterway. The area saw little activity until the Second World War, when the Navy established the Banana River Naval Air Station fifteen miles south of the Cape. After the war, activity declined until the Air Force selected Cape Canaveral as the western end of its new Long Range Proving Ground and supported it by constructing Patrick Air Force Base on the site of the naval air station.[73]

The location proved ideal for testing cruise missiles and, later, launching ballistic missiles and space flights. Launches in a southeasterly direction avoided major population centers by passing over islands that served as tracking stations along a 7,500-mile course from the Bahamas to Ascension Island in the South Atlantic to the coast of Africa. As a result, burned-out missile stages and expendable boosters avoided densely populated land areas. Moreover, with an easterly launch the earth's rotation added greater velocity, which enabled boosters to orbit heavier loads. In the 1960s the Cape underwent an enormous buildup resulting especially from NASA's rapid expansion and the Air Force's development of the Titan III. The Eastern Test Range became the center for Vela and communications satellite launches as well as NASA's Mercury, Gemini, and Apollo manned flights and all American spacecraft launched eastward into low-inclination equatorial orbits.[74]

The Western Test Site at Camp Cooke, later Vandenberg Air Force Base, California, also began operating as a missile test base. In 1956, the Air Force selected the Army's old Camp Cooke, which extended over twenty-five miles along the coastline some sixty miles west and north of Santa Barbara. Used for testing ICBMs and IRBMs, it became part of the Pacific Missile Range, which also encompassed the Navy's Point Mugu between Santa Barbara and Los Angeles. In 1958, when the Air Force renamed Camp Cooke Vandenberg Air Force Base, Lockheed already had started work on the Agena upper-stage spacecraft. Officials selected the California site for launching satellites into near-polar orbit. Missiles and reentry vehicles launched westerly over the South Pacific and space boosters launched in a southerly direction avoided population centers on their path into high-inclination polar orbits, which proved essential for effective satellite coverage of the Asian landmass. As a result, the Western Test Site became the location for the nation's high-inclination sun-synchronous surveillance missions and, from 1971, the designated location for proposed near-polar-orbit Space Shuttle operations. Like its eastern counterpart, the western range depended on a long line of space tracking stations stretched across the Pacific from California to the South and Southeast Asian coasts. The Western Test Range served as the launch site for the important Samos, CORONA, MIDAS, and DMSP satellites that required near-polar orbits.[75]

A second group of space facilities comprised the tracking network and its control center that made possible the crucial integration of satellites, launch sites, and processing centers. Designated the Satellite Control Facility (SCF), it included a global system of remote tracking, telemetry, and command stations, a central control center sited in California, and the communications links that bound together all the equipment and software needed to track and control spacecraft during launch, orbit, descent, and recovery.[76]

Tracking stations functioned effectively only when satellites remained in range of the ground antennas. Because this time was brief for satellites in low orbits, ground stations were scattered widely but tied to the control center. By the end of the 1960s, the Air Force relied for its space operations on six key radio tracking and command stations, located in 1959 at Vandenberg Air Force Base and New Boston, New Hampshire; Thule, Greenland, in 1961; Mahe Island in the Indian Ocean in 1963; Guam in 1965; and the oldest, Kaena Point on the island of Oahu, Hawaii, in 1958. The last proved especially valuable in recovery of CORONA reconnaissance film capsules. During the 1960s, the Air Force worked to standardize and upgrade tracking site operations and equipment. This included use of a standard Defense Department telemetry, command and control system designated the Space-Ground Link Subsystem, and adoption of two uniform dish antennas measuring between forty-six and sixty feet in diameter that could pivot rapidly to monitor low-earth satellites.[77]

The control center, the second element in the SCF network, received the designation Satellite Test Center. The Air Force's early and close relationship with Lockheed led to locating the command center in Sunnyvale, near Palo Alto, California. The first center in 1959 amounted to little more than several rooms with plotting boards next door to Lockheed's computer complex in Palo Alto, where members of the 6594th Test Wing (Satellite) successfully controlled the first Discoverer flight in 1959. By June 1960 the Air Force had constructed a permanent facility eleven miles away in Sunnyvale. After another year of equipment improvements, the Satellite Test Center could support three satellite missions at once with its two Control Data Corporation (CDC) 1604 computers. Improvements continued throughout the 1960s. In 1965 the Air Force replaced the single control room with separate rooms for each flight. Over the next three years, the center upgraded its computer capability with five CDC 3600 and seven CDC 3800 computers to handle the increasingly complex software programs and growing satellite population. Early advances culminated in 1968 with completion of the so-called "Blue Cube," a new ten-story windowless "Advanced Satellite Test Center" scheduled to handle Manned Orbiting Laboratory flights. With cancellation of the Air Force's manned mission in 1969, however, the Blue Cube provided controllers vastly increased capabilities to support, twenty-four hours per day, seven days per week, real-time operations for instrumented satellite missions. Statistics help explain the phenomenal development in command and control capability. In 1960 the Satellite Test Center recorded 300 satellite contacts and 400 hours of flight operations. Fifteen years later, Satellite Test Center ground stations logged 52,445 hours and made contact with more than 30 satellites a total of 60,536 times.[78]

The communications network represented the third element of the Satellite Control Facility. For the initial Discoverer flight in 1959, it consisted only of landlines, radio links, and submarine cables that connected the Satellite Test Center with tracking stations confined to the continental United States, Alaska, and Hawaii. In 1962 the Air Force extended to its overseas stations secure circuits capable of 100 words per minute. During the next two years, a "multiple satellite augmentation program" provided the Sunnyvale Satellite Test Center with high-frequency radio capability through four independent voice channels and the addition of twenty-eight teletype machines, with transmission links to the remote tracking stations.[79]

The Satellite Control Facility's communications network underwent dramatic improvement with the launch of the first seven military communications satellites in June 1966. Each of the satellites in the Initial Defense Communications Satellite Program could transmit 600 voice or 6,000 teletype channels. With the addition of eight more satellites in January 1967, the Air Force could implement its "advanced data system" communications net designed to support the more challenging near-real-time command and control operations from the Blue Cube. A new sixty-foot dish antenna located at Camp Parks Communications Annex near Oakland, California, served as the network terminus. By 1970 the Camp Parks facility passed all data it received directly to the Sunnyvale control center over land lines and microwave relay links. In the future, the larger, more powerful satellites of the DSCS II program promised a wideband satellite relay communications system capable of transmitting 1.5 million bits of data per second. In less than a decade, the Satellite Control Facility had proven capable of expanding to meet the challenging demands of a burgeoning space community.[80]

Organization Provides the Focus for Space

The rapid growth of Air Force space infrastructure during the 1960s compelled planners to provide new, more effective organizational structures for range management, launch and on-orbit authority, payload recovery, and operational command and control of satellite systems. With the establishment in 1961 of Air Force Systems Command as an independent management headquarters for space and all Air Force research and development, it came as no surprise to find organizational responsibility for Air Force space resources increasingly associated with AFSC and its focal point for space, the Space Systems Division, and its successor organizations.

First came reorganization of the Atlantic and Pacific ranges. In January 1964, AFSC created the National Range Division (NRD), with provisional headquarters at Patrick Air Force Base, Florida. This followed agreement with NASA on range responsibilities in early 1963 and, later in the year, Secretary McNamara's decision to transfer Pacific Missile Range responsibility from the Navy to the Air Force and to assign the worldwide satellite tracking network to the Air Force. The National Range Division assumed responsibility for coordinating Defense Department and NASA activities at both the eastern and the western launch sites, and it established a provisional Air Force Space Test Center (AFSTC) at Vandenberg Air Force Base to manage Pacific Range activities. In January 1964, the National Range Division also gained the Air Force Satellite Control Facility at Sunnyvale, California. In May, the Air Force relocated the division to the site of Air Force Systems Command headquarters at Andrews Air Force Base, Maryland, near Washington, D.C., and redesignated the two ranges as the Eastern Test Range and the Western Test Range. Operations at Sunnyvale, however, proved awkward, with AFSC exercising direct control of the range, while Space Systems Division retained on-site responsibility for launch operations. A reorganization in July 1965 reassigned the Satellite Control Facility to Space Systems Division at Los Angeles.[81]

Following the establishment of the Space and Missile Systems Organization (SAMSO) on 1 July 1967, which recombined Air Force missile and space functions in a single entity, additional organizational changes served to enhance the space role of the Los Angeles headquarters. On 1 April 1970, by forming the Space and Missile Test Center (SAMTEC) at Vandenberg Air Force Base, California, the Air Force centralized all launch operations at the Pacific site for the first time. By assigning SAMTEC to SAMSO, the Los Angeles headquarters became responsible for nearly all military space program facilities. The consolidation became complete seven years later when, on 1 February 1977, the assignment to SAMSO of the Eastern Test Range at long last brought all space and missile launch facilities under one organization.[82]

The organizational changes of the 1960s helped lay the groundwork for Space Systems Division and later SAMSO to direct the development of the unmanned communications, weather, navigation, and early warning satellite programs that made the military community increasingly aware of, and dependent upon, space systems. At the same time the organizational developments enhanced the control of a research and development command over space systems that were becoming increasingly operational.

Vietnam Offers the First Military Space Test

Satellites first demonstrated their tactical battlefield defense support capability in Vietnam. There, meteorological and communications satellites provided vital near-real-time data essential for mission planning and execution. During a nationally-televised CBS interview in May 1967, General William Momyer, the Seventh Air Force Commander declared:

> As far as I am concerned, this weather picture is probably the greatest innovation of the war. I depend on it in conjunction with the traditional

> forecast as a basic means of making my decisions as to whether to launch or not launch the strike. And it gives me a little bit better feel for what the actual weather conditions are. The satellite is something no commander has ever had before in a war.[83]

Indeed, weather satellites proved to be an invaluable feature and key innovation of the war. Air missions in Southeast Asia often depended for success on the availability of a cloud-free environment for low-level fighter, tanker, and gunship operations. Few in number and limited by the dangers of operating in or over hostile territory, conventional weather sources proved inadequate to the challenge. Satellite imagery, relayed throughout the region, provided the answer.

The Air Force did not furnish the only satellite weather data for Allied forces in Southeast Asia. In the mid-1960s Nimbus satellites developed by NASA for the Weather Bureau used their Automatic Picture Transmission capability to transmit imagery from their sun-synchronous orbits daily between 0700 to 0900 and 1100 to 1300 hours. Beginning in 1965 DMSP imagery proved more useful to Air Force and Navy meteorologists and mission planners. From an altitude of 450 NM, the sun-synchronous satellites furnished day and night, visual and infrared imagery consistently at 0700, 1200, 1900, and 2400 hours local time. DMSP data, however, did not become available to the Navy until 1970, when the *USS Constellation* acquired the necessary readout equipment. With timely, accurate satellite weather data available, planners knew when the weather would break over a target area, and used night-sensor imagery to determine the extent of burning rice paddies to forewarn pilots of likely smoke coverage. Weather information proved especially useful in the Navy's lengthy effort to destroy the important Thanh Hoa Bridge in North Vietnam. The Son Tay raid to rescue American POWs in 1970 also depended on satellite imagery. In this case DMSP data provided extremely accurate three-to-five-day forecasts that allowed the planners to schedule the raid to coincide with a break in two tropical storms moving across the South China Sea onto the mainland.[84]

Communications satellites also proved their worth in Vietnam, where for the first time satellite transmissions provided communications from a real-world theater of operations. In June 1966, a satellite communications terminal operated from Ton Son Nhut Air Base using the limited one-voice and one-record circuit capability of the NASA-developed Synchronous Communications Satellite. It operated between Saigon and Hawaii until its demise in 1967 owing to satellite drift. Improvements arrived with the installation of two ground terminals at Saigon and Nha Trang to support the Initial Defense Communications Satellite Program (IDCSP). Operational by July 1967, each terminal had expanded from five to eleven circuits by January 1968. Under Project Compass Link, IDCSP provided circuits for transmission of high-resolution photography between Saigon and Washington, D.C. As a result of this revolutionary development, analysts could assess near-real-time battlefield intelligence far from the battlefield. On the other hand, this raised questions of major import for command and control of operational forces. Although IDCSP satellites made possible more centralized operational control, at this time they also comprised part of a vulnerable system connecting a number of remote terminals with a single central terminus.[85]

Commercial systems also supplied satellite circuits to support area communications requirements. The Communications Satellite Corporation (COMSAT) leased ten circuits between its Bangkok facilities and Hawaii, while the Southeast Asia Coastal Cable system furnished part of the network for satellite terminal access between Bangkok and Saigon. Satellite usage during the Vietnam conflict established the military practice of relying on commercial space systems for routine administrative and logistical needs while trusting more sensitive command and control communications to the dedicated military system.[86]

Communications and weather satellites brought space into the realm of combat operations. They provided much needed real-time weather information and communications support to battlefield commanders and planners in Vietnam, and they linked them regionally and globally. Weather and communications satellites established their operational value for future defense support combat—as well as peacetime—operations.

The Military Space Community in Transition

For the burgeoning Air Force space program, the decade of the 1960s represented a transitional period in which experimental programs became effective operational systems. By the end of the decade communications and weather satellites operated by the Air Force provided crucial information to commanders in Vietnam. Air Force-led engineers found themselves on the brink of developing a three-dimensional satellite navigation system that promised to revolutionize battlefield command and control capabilities. In the area of surveillance, the early 1970s witnessed the operation of Air Force infrared early warning satellites that immediately became the central element in the nation's missile warning network. Already Air Force-developed Vela nuclear detection satellites helped make possible verifiable nuclear test ban treaties and potential arms limitation agreements. In this, as in more sensitive areas of strategic intelligence, automated satellites made an invaluable contribution to strategic reconnaissance and thereby considerably diminished the ability of any nation to launch a surprise attack. Unmanned, instrumented satellites had largely met the military requirements that President Eisenhower had set in the 1950s for a major missile and satellite program.

By the early 1970s military space had come of age. Both within the Air Force and among the other services and defense agencies, the contribution of space-based systems to the Vietnam war, as well as a growing range of peacetime defense support requirements, led to increased acknowledgment, if not acceptance, of space operations. This, however, set the stage for a return to the intense service competition of the Eisenhower era. The Defense Department traditionally sought to avert service rivalries through joint funding and management ventures and by designating the Air Force the service for military space research and development. Policy promulgated by the Office of the Secretary of Defense effectively stymied Air Force efforts to gain sole responsibility for military space activities, while joint management did not always prove successful—or diminish the voice of congressional critics of separate civilian and military systems. Although interservice competition remained muted for much of the 1960s, it certainly did not disappear.

This became clear at the end of the decade when the Navy reopened the issue of space management responsibility by challenging the Air Force monopoly on space development. In the Navy's view, the 1961 directive had become outdated and only served to prevent wider exploitation of space for important military requirements. Back in 1960, Air Force Chief of Staff General Thomas D. White fended off the Navy's Admiral Arleigh Burke by arguing that the Air Force would provide effective leadership for the nation's space program and be responsive to the needs of the other services. In 1970, General White's successors could point to a decade of successful, responsible management for the benefit of all the services. But with space programs providing support to an increasing number of users throughout the military community, the dominant Air Force position came under fire from the other services and their allies in Congress and the Defense Department.

Unconvinced by Air Force arguments, Secretary of Defense Melvin Laird, on 8 September 1970, issued Directive 5160.32, which declared that space systems would be acquired and assigned according to the guidelines pertaining to other defense weapon systems. Ongoing programs, however, would remain unaffected. As a result, the Air Force would retain responsibility for developing and deploying "space systems for warning and surveillance of enemy nuclear delivery capabilities and all launch vehicles, including launch and orbital support operations." On the other hand, all three services could now compete "equally" for future programs, including "communications, navigation, unique surveillance (i.e., ocean or battlefield), meteorology, defense/offense, mapping/charting/geodesy, and major technology programs." While this provision reinforced traditional naval interest in ocean surveillance and navigation and the Army's preeminence in geodesy, it left open the question of future management responsibility and operational relationships for communications (DSCS), battlefield command and control (GPS), weather (DMSP), and the crucial area of "major technology programs."[87]

Rather than attempt to overturn the directive and fight to reclaim the Air Force space monopoly, Air Force Secretary John McLucas wisely chose to focus on its portent for unbridled competition in the other services and agencies. Such groups, he warned, would likely bypass the Air Force and its vast reservoir of space resources and experience, and the resulting duplication and wastefulness would not be in the nation's best interests. On this issue, Secretary McLucas could refer to the often unmentioned, yet impressive, range of research and development activities that had characterized Air Force space efforts during the 1960s in support of a wide range of NASA and Defense Department requirements. These would include rocket testing at Edwards Air Force Base, California, Agena target analysis at the Arnold Engineering Development Center in Tennessee, and the fundamental work done by associate contractors on environmental and system testing projects, normally in conjunction with Air Force Systems Command offices and laboratories. Highlighting the latter efforts would be the development of solid and liquid rocket technology for both NASA and the Defense Department.

Impressed by McLucas' argument, Secretary Laird in February 1971 modified the 1970 decision by directing that all space program development be coordinated with the Air Force beforehand. The Defense Secretary's revision and the work of Secretary McLucas and other Air Force leaders to cooperate on space defense matters helped to mute the impact of the original directive for the immediate future. Nevertheless, the door now stood open to fierce competition for scarce space resources and for control of space systems increasingly important to ever-larger numbers of users.

To retain its space supremacy, the Air Force now needed to get its own house in order. Space systems demanded less emphasis on lengthy control by research and development agencies and more focus on operational organizational and management decisions. The advent of the Space Shuttle in the 1970s would compel the Air Force to face this challenge. Development and operational control of the Shuttle involved intense competition among Air Force commands, while interservice rivalry and civil-military management issues remained unresolved. The Space Shuttle would serve to crystallize the thinking of the Air Force community on space issues in the decade ahead. Unmanned, instrumented space systems had brought space to the operational threshold. It remained for Air Force leaders to determine the proper place for space within the traditional Air Force.